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ESTIMATING WATER NEEDS OF SOYBEAN (GLYCINE MAX) USING THE PENMAN MODEL METHOD IN UMUDIKE SOUTHEASTERN, NIGERIA

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ABSTRACT

Understanding water needs is essential for irrigation scheduling and water saving measures in Umudike, southeastern Nigeria. This study was performed using the Penman's methods to predict seasonal changes in evapotranspiration (ETc) for soybean fields in Umudike in 2012. Results obtained in this study showed that seasonal crop evapotranspiration for soybean production (July - November) was 344.51 mm. The irrigation water requirement (IR) was zero for July, August, September and October, while that of November was 3.03. In the months of July through October, effective rainfall (ER) was higher than water need of the crop (ETcrop) except for November, suggesting that supplemental irrigation may be required in the month of November during pod filling/ripening stage.

KEYWORDS: Crop Coefficient, Crop Water Consumption, Irrigation Water Requirement, Soybean, Phenological Stages

INTRODUCTION

Soybean *(Glycine max [L.] Merr.)* is an important high value grain legume food in the diet consumed in many house-holds of the people, and a raw material for many agro-based industries in Nigeria (FAOSTAT, 2001). The crop is also grown for edible vegetable oil and high protein feed supplements for poultry and livestock industries particularly in the face of the current official restriction on the importation of raw materials used by these industries. The seeds have substantial economic importance in a wide range of industrial, food pharmaceutical and agricultural products (Smith and Huyser, 1987; FAO, 1978; 2002). World production (FAOSTAT, 2001) of soybean stood at about 176.6 million tons in over 75.5 million ha. The United States is the principal world supplier of soybean (Jewell, 1988).

Availability of essential nutrients is influenced by soil pH through its effects on Al saturation percentage and on nutrient fixation and release mechanisms. Highest soybean yields are usually produced when soil pH is between 6.2 and 7.0. In this range, adequate Ca and Mg are normally available. Soybeans grown on naturally acid oxisols and ultisols will generally produce to their potential at soil pH between 5.5 and 6.5. However, liming of these soils should also reflect the importance of exchangeable aluminum. Soils with low exchangeable Al with no soil solution Al generally will not benefit from lime application. This usually occurs at a soil pH of 5.5 or greater.

The crop is widely cultivated in the tropics and sub-tropical region of West Africa, characterized by erratic rainfall pattern and periodic dry spells. Soybean is basically a short-day plant, but response to day length varies with variety and temperature. The crop is adapted to a wide range of climatic conditions. It is most susceptible to drought damage during flowering and grain filling. It is not generally irrigated.

Climate is an important environmental factor that influences what crop that can be grown in any particular location (Watson, 1963). Of all the climatic variables, availability of moisture throughout the growth cycle of a crop is an index of crop suitability to particular agro ecology. This is because; water is a raw material of photosynthesis (Lawlor, 1995) and therefore forms the basis for crop growth and yield. However, both excess and inadequate moisture supply to crops is detrimental to optimal yield and crop quality (Bauer *et al*., 2003). The belief that humid regions have adequate water for rain-fed agriculture comes from the assumption that the annual rainfall provides sufficient water for plants to grow, given evaporation occurring. The problem with this assumption is that it does not consider the temporal distribution of rainfall and large amounts of water will not stay in the soil long enough to be used by plants (Ritchie, 1994). However, the effective rainfall or the portion of rainwater that infiltrates into the soil and used for crop production (Stewart, 1980) is of more importance for rain-fed agriculture. Adequate water must therefore be available for germination, and during flowering and early yield formation (pod development), particularly the later part of the flowering period and early part of the pod development.

Water requirements (ETm) for maximum production of soybean ranged from 450-700mm (FAO, 1986; 2002), well distributed over the growing season. The crop needs frequent watering especially early yield formation (pod development). Water deficits just prior and during flowering and early yield formation (pod development) may cause heavy flower and pod dropping (FAO, 1986). Therefore for normal pod filling and high yield the soil water during the yield formation period should not exceed the 50% depletion level. Increasing crops productivity and saving irrigation water are two interrelated issues raising a lot of concern these days in this region.

The most important times for soybean plants to have adequate water are during pod development and seed fill (Kranz *et al.*, 1998). These are the stages when water stress can lead to a significant decrease in yield. Stressful conditions, such as moisture deficiency reduces soybean yield. Water deficits, and the resulting stress on the plant, have an effect on crop evapotranspiration and crop yield. When the full crop water requirements are not met, water deficit in the plant can develop to a point where crop growth and yield are affected. As the soybean plant ages from beginning bloom through seed enlargement, its ability to compensate under stressful conditions decreases and yield losses could increases (Foroud *et al.,* 1993). However, crop water use is influenced by prevailing weather conditions, available water in the soil, crop species and growth stages. Water deficits, and the resulting stress on the plant, have an effect on crop evapotranspiration and crop yield. When the full crop water requirements are not met, water deficit in the plant can develop to a point where crop growth and yield are affected. Actual evapotranspiration (ETa) equals maximum evapotranspiration (ETm) when available soil water to the crop is adequate, or ETa = ETm, and ETa < ETm, when available soil water is limited.

Soybean develops a rooting system that may extend to a depth of over 1.5m (FAO, 1986 and Al-kaisi and Broner, 2005). The crop can effectively draw all the available soil water up to 1.8m. Under a restricted soil depth, the tap root may be less pronounced and lateral roots will be more developed. Although the roots are generally concentrated in the first 0.6 m or even sometimes the first 0.3 m, considerable soil water, particularly during the later growth periods, can be extracted from the lower parts of the root zone. However, under normal conditions 100% of the water uptake comes from the first 0.6 to 1.3 m soil depth (D = 0.6 - 1.3 m). The demand for water by the crop must be met by the water in the soil via the root system. Understanding the crop water needs is essential for irrigation scheduling and water saving measures during the dry period of the cropping season. This means that the amount of water stored in the soil must be equal to the

loss of water by evapotranspiration, since soybean require large amount of water for pod filling, it is necessary to know the exact water requirements to judiciously consider the economics of soybean production. The FAO irrigation and drainage paper 24 (Doovenbos and Pruitt, 1977) provided tables needed to calculate ETo using temperature, relative humidity, wind and sunshine records.

Consequently, the soybean crop undergoes moisture stress quite a few times during its growing season. Modeling water consumption in field crops is a key point for better irrigation management. The knowledge of soybean water requirement along with precipitation characteristics of the region will permit proper timing of planting in order to secure sufficient moisture during flowering and to allow harvesting to coincide in a period with a high probability of dry weather. Considering paramount importance of proper use of irrigation for high yields, the present study was designed to investigate the crop water requirements and irrigation water requirements of soybean in Umudike area of Abia State, Nigeria using Penman's equation model.

MATERIALS AND METHODS

This study was carried out at the Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Umudike is located in the humid forest zone of Nigeria and lies within latitude 05^0 29' N and longitude 07^0 33' E (Chukwu, 1999) with and altitude of 122 m above sea level. Annual rainfall in Umudike ranges from 1900mm to 2200 mm, bimodal distributed with peaks in July and September. The soil is Sandy clay loam (coarse textured) and classified as an Ultisol (Njoku *et al*, 2001) cited by Iren and Osodeke (2006).

Metorological data on rainfall (amounts and days), Relative humidity (maximum and minimum), temperature (maximum and minimum), sunshine and wind speed covering ten (10) years (2003-2012) were collected and analyzed. These helped in obtaining the reference crop evapotranspiration (ETo), crop coefficient (Kc), maximum evapotranspiration (ETm), and irrigation water requirement (IR).

Crop Water Requirements

The weather data used for this study cover the period from 1998 to 2007 and was collected from the meteorological station of the National Root Crop Research Institute, Umudike. The climatic data (Table 1) were used to calculate the reference or potential evapotranspiration (ETo). Reference evapotranspiration (ETo) is defined as the rate of evaporation of an extended surface of 8 – 15 cm tall green grass cover, actively growing, completely shading the ground and not short of water (FAO, 1986). It represents the climatic evaporation demand and predicts the effect of climate on crop. An average growth period of 135 days or more (FAO, 1986) was disaggregated into 20, 30, 60 and 25 days representing respectively, the establishment, Vegetative, flowering and maturity stages (FAO, 1986). The crop was assumed to have been sown within the recommended periods at the Michael Okpara University of Agriculture Research and Training Centre, Umudike on the 1st of July and harvested on the 12^{th} November, 2012. The estimation of crop evapotranspiration involved 3 stages.

Calculation of Reference Crop Evapotranspiration (ETo)

The reference evapotranspiration (ETo) was computed based on Penman's (1948) equation and modified by Allen *et al.* (1994) to predict the crop water requirement (FAO, 1986). Since this method considered several climatological data in its computation, Makadho and Butlig (1989) considered it the most satisfactory method of estimating evapotranspiration

relative to other methods available. The equation is given as follows:

Eto=c [W.Rn+ (1-W)-f (U). (ea-ed] (1)

Where

ea-ed = vapour pressure deficit i.e the difference between saturation vapour (ea) at Tmean in mbar and actual vapour pressure (ed) in mbar where ed = ea.RH/100 f(U) = wind function of f(U) = 0.27 ($1+U^1/100$) with U in km/day measured at 2m height

Rn = total net radiation in mm/day or Rn = 0.75Rs – Rnl where Rs is incoming shortwave radiation in mm/day either measured or obtained from Rs = (0.25+0.50 n/N) Ra. Ra is extra-terrestrial radiation in mm/day, n is the mean actual sunshine duration in hour/day and N is maximum possible sunshine duration in hour/day.

Rnl is net longwave radiation in mm/day and is a function of temperature, f (T), of actual vapour pressure f(ed) and sunshine duration f (n/N); or Rnl = f (T). f (n/N). F(ed).

W = temperature and altitude dependent weighting factor

c= adjustment factor for ratio U day/U night, for RH max and for Rs.

Crop Coefficient (Kc)

Crop coefficients (Kc) of 0.35, 0.75, 1.10 and 0.6 for establishment, Vegetative, flowering and maturity growth stages respectively (FAO, 1986). The Kc value varies with crop development stage of the crop, and to some extent with wind speed and humidity. For most crops, the Kc value increases from a low value at time crop emergence to a maximum value during the period when the crop reaches full development, and declines as crop matures (FAO, 1986).

Empirically: Determined crop coefficient relates reference evapotranspiration rate (ETo) to the maximum evapotranspiration rate (ETm) when water supply fully meets the water requirements of the crop. This was obtained based on the date of sowing of the crop, the length of the total growing season disaggregated into:

- Duration of the early growth or initial stage (germination to 10% ground cover)
- Duration of peace vegetative growth or the crop development stage (from 10 to 80% ground cover)
- Duration of flowering and pod formation or the mid-season stage (from 80% of ground cover to start of ripening) and,
- Duration of physiological maturity or late season stage (from start of ripening to harvest).

Crop coefficient (kc) for various crops are presented in Doorenbos and Pruitt (1977) and modified by Doorenbos and Kassam (1979). Crop coefficient (Kc) of 0.35, 0.75, 1.10, and 0.60 were used for the initial, crop development, mid season and late season stages, respectively.

Maximum Evapotranspiration (ETm)

Crop evapotranspiration (ETcrop) refers to conditions when water is adequate for unrestricted growth and development (Allen et al., 1998) *i.e*, when soil water is not limited, also called water requirements in mm/day or mm/period. Crop evapotranspiration (ETm or ETcrop) was determined as:

$$ET\ crop = ETo \times Kc \quad (2)$$

The kc value at each stage of the growth stages was converted to monthly Kc as:

$$Kc/month = \frac{kc\ growth\ stage \times N}{30} \quad (3)$$

Where

N = number of days growth stage lasted in a month and each month was assumed to have 30 days.

Crop evapotranspiration (ETcrop/ month) was obtained as the product of the monthly mean ETo in mm/day and the kc for the crop over each 30-day period. Seasonal ET crop values were calculated by summing the monthly values.

Irrigation Water Requirement (IR)

This was calculated as the difference between ETm and Effective Rainfall (ER) using the formular of Brouwer and Heibloem (1986). Effective Rainfall (ER) was calculated as follows:

$$ER = 0.8r - 25, \text{ if } R > 75mm / month \quad (4)$$

Or

$$ER = 0.6R - 10, \text{ if } R < 75mm / month \quad (5)$$

Where:

ER = Effective rainfall or the part of the precipitation that is infiltrated and stored in the root zone and which plants can depend on to satisfy the water needs.

R = Monthly rainfall.

When the actual evapotranspiration (ETa) is less than the maximum evapotranspiration (ETm), there is moisture deficit. To know when to irrigate, irrigation interval (IN) was calculated as:

$$IN = \frac{P \times D \times Sa}{ETcrop} \quad (6)$$

Where:

P = Soil water depletion factor (FAO, 1986) for crop groups and maximum (ETm)

D = Rooting depth (0.6m)

Sa = Total available soil water (FAO, 1986 and 1992), 60 mm/m for coarse textured soil as is found in Umudike soils.

The potential yield response to water supply was calculated as outlined by Dooernbos and Kassam (1979) cited in FAO (1992) as:

$$1 - Ya/Ym = Ky \times 1 - ETa/ETm \quad (7)$$

Where:

Ky = Yield Response Factor

Ya = Actual Yield Harvested (tonnes/ha)

Ym = Maximum Harvested (tonnes/ha)

ETa = Actual Evapotranspiration (mm/day)

ETm = Maximum Evapotranspiration (mm/day)

To calculate ETa at different water deficit

ETa = ETm - %water deficit of ETm at different growth stages (8)

RESULTS AND DISCUSSIONS

Table 1 presents the climatic data of Umudike. From the table, daily reference evapotranspiration (ETo) varied from 2.26 to 4.04 mm/day with a mean of 3.54 mm/day, while the monthly ETo varied from 70.06 to 124.93 mm/month with a mean of 107.58 mm/month. The ETo where higher in the months of March, April, and May but lower in the months of August and September. Similar trends were recorded by Chukwu (1999). Table 2, shows the lengths of crop development stages for soybean at Umudike. The reproductive growing stage has the longest length of days of growing period (60 days) relative to establishment and maturity stages which have 20days and 25days respectively. The reproductive period was also observed to have the highest crop evapotranspiration (204.83) and crop coefficient (2.10) values relative to establishment stage (23.24 and 0.23) and maturity stage (54.52 and 0.50) for ETm and Kc and these have 20days and 25days respectively as presented in Table 5. The reproductive phenology represents the most active growth stage as reported by Salter and Goode (1967), FAO (1986), and Reamaekers (2001) in the cultivation of soybean.

The calculated monthly crop coefficient (Kc/month) values for soybean where; 0.51, 0.92, 1.10, 0.92 and 0.24 for the months of July, August, September, October and November respectively (Table 2) while the crop coefficient (Kc/period) were 0.23, 0.76, 2.10 and 0.50 for the growth stage of establishment, vegetative, reproductive and maturity phonological stage, respectively (Table 5). The results shows that as the crop developed its vegetative cover by increasing the foliage, the Kc also increased progressively and it reached peak during reproductive stage at 50 – 110 days of crop age. Then it started decreasing as the crop advanced toward maturity. This result is similar to that of reports presented by FAO (1986) and chukwu 1999, where Kc values increases from a low value at time of crop emergence to a maximum value during the period when the crop reaches full development, and declines as the crop matures. The highest kc values were observed in the months of August, September and October (0.92, 1.10 and 0.92) for the season. These months coincide with the vegetative and reproductive stages of growth in soybean production which are reportedly the most active growth stages (FAO, 1986, Reamaekers, 2001).

Table 4 shows the crop evapotranspiration (ETcrop), effective rainfall (ER), different between ER and ETcrop, irrigation water requirements (IR) and irrigation interval (IN) of soybean production in Umudike. FAO (1978) reported that the length of growing period is the number of days when precipitation exceeds half the potential evapotranspiration. Using 135 days maximum growth duration, an average of 103 mm of moisture is found to be the maximum crop evapotranspiration (ETm) of soybean. This is an indication of soybean's water needs throughout its life cycle in Umudike. A minimum crop evapotranspiration of 26 mm is found for November with atmospheric temperature of 32^0c. The effective rainfall was higher than the water requirements for soybean throughout the growth period indicating that there was no need

for irrigation throughout the growth period. Conversely, effective rainfall was lower than the water requirement of the crop in the months of Nov and Dec (Table 4) for the soybean cultivation. This indicates that supplemental irrigation was needed during these months. In the month of Nov (Table 4), irrigation water requirement (IR) was 3.03mm for soils of Umudike. The effect of water deficit on yield during the period was greater because of the relatively high temperature and low humidity for this period as shown in Table 1.

CONCLUSIONS

Crop water requirements of soybean in Umudike can be met by effective precipitation if sowing date falls between July and October. The overall results showed that, crop water requirement (ETcrop) in Umudike soils was higher in the month of September during the period of vegetative and reproductive stages. Soybean sown in November in Umudike will encounter water deficit stress in all but the physiological maturity and harvest stages of the crop cycle. Irrigation water requirements to mitigate these deficit stresses vary depending on the period of cultivation. Since soybean is sensitive to water during the early growing period which can adversely affect yields it is therefore proper to cultivate at the appropriate time, so that the establishment, vegetative and reproductive stages coincide with period when the is sufficient supply of water, otherwise sowing any date from September to March will require supplemental irrigation with the greatest shortage in December to February cropping period. In view of excess moisture availability beyond the optimal crop requirements special farming techniques may be necessary to ameliorate the impact of excess moisture on growth and yield of soybean during any sowing date between April and August.

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APPENDICES

Table 1: Mean of 10 Years Climatic Data of Umudike (from 1997 to 2006)

Months Rainfall (mm)		Days (mm)	RH Max %	RH Min %	RH Mean %	Max Temp (^0C)	Min Temp (^0C)	Mean Temp (^0C)	Sunshine Duration (hr/day)	Wind Speed (km/hr)	U Day m/ sec	U Night m/sec	U Day/ U Night m/sec	ETo mm/Day	ETo mm/ Month
Jan.	16.65	2	58.38	40.29	49.34	32.6	21.7	27.20	4.82	9.50	3.0	2.0	1.5	3.71	115.01
Feb.	47.41	2	69.86	45.86	57.86	34.3	22.9	28.60	5.19	10.20	„	„	„	3.76	105.28
Mar.	86.86	6	76.86	56.00	66.43	33.9	23.6	28.75	4.29	10.20	„	„	„	4.03	124.93
Apr.	172.37	11	80.14	64.71	72.43	32.9	23.9	28.40	5.23	8.80	„	„	„	4.04	121.20
May	261.05	15	81.71	70.14	75.93	31.9	23.3	27.60	5.63	8.80	„	„	„	4.00	124.00
June	314.02	18	85.00	74.71	79.86	30.6	22.9	26.75	4.53	8.80	„	„	„	3.48	104.40
July	304.30	21	86.57	67.57	77.07	29.6	22.8	26.20	3.18	9.50	„	„	„	3.26	101.06
Aug.	264.99	19	74.71	68.14	71.43	29.2	22.7	25.95	2.37	8.80	„	„	„	2.26	70.06
Sept.	324.07	21	85.29	76.71	81.00	29.7	22.6	26.15	2.70	8.80	„	„	„	3.14	94.20
Oct.	262.77	18	83.14	73.00	78.07	30.7	22.7	27.70	3.75	8.80	„	„	„	3.44	106.64
Nov.	56.25	4	80.57	55.43	68.00	32.0	23.0	27.50	5.08	8.80	„	„	„	3.72	111.60
Dec.	4.21	1	73.00	50.57	61.79	32.0	21.5	26.75	5.57	9.50	„	„	„	3.63	112.53
Total	2114.95	138	934.99	743.01	839.21	379.4	273.6	326.5	49.64	110.5	„	„	„	42.47	1290.91
Mean	176.25	12	77.92	61.92	69.94	31.62	22.80	27.21	4.14	9.20	„	„	„	3.54	107.58

Key: ETo = reference crop evapotranspiration. Max = maximum. Min = minimum. Uday = day wind speed. Nday = night wind speed. RH = relative humidity

Table 2: Phenology and Lengths of Crop Development Stages for Soybean at Umudike in 2006

Growing Stage	Date of Phenology	Length (Days)
Plant date	July 1	
Establishment stage	From July 1 to 10% vegetative cover (July 20)	20
Vegetative stage	From July 21 to initiation of flowering (August 19)	30
Reproductive stage	From August 20 to start of maturity (October 18)	60
Maturity stage	From October 19 to harvest (November 12)	25
Harvest date	November 12	
Total length		135

Table 3: Monthly Crop Efficient (Kc/Monthy) for the Soybean Production in Umudike

Growing Period	Reference Evapotranspiration (ETo/Month)	Monthly Crop Coefficient (Kc/Monthy)
July	**101.06**	**0.51**
August	**70.06**	**0.92**
September	**94.20**	**1.10**
October	**106.64**	**0.92**
November	**111.60**	**0.24**

Table 4: Crop Evapotranspiration (ETcrp), Effective Rainfall (ER), ER–Etcrop and Irrigation Water Requirement (IR) of Soybean Production in Umudike

Growing Period	Crop Evapotranspiration (ETcrp) (mm/Period)	Effective Rainfall (ER)(mm)	ER – Etcrop	Irrigation Water Requirement (IR)	Irrigation Interval (IN) for Coarse Textured Soil in Umudike
July	51.54	218.44	166.90	0.00	
August	64.46	186.99	122.53	0.00	
September	103.62	234.26	130.64	0.00	
October	98.11	185.22	87.11	0.00	
November	26.78	23.75	-3.03	3.03	
Seasonal values	344.51	848.66	504.15	3.03	

Table 5: Crop Evapotranspiration (ETcrp) of Growth Stages for Soybean Production in Umudike Phenological Stages

	ET Crop	Kc
Establishment stage	23.24	0.23
Vegetative stage	61.93	0.76
Reproductive stage	204.83	2.10
Maturity stage	54.51	0.50